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Dialogue and materiality/embodiment in science|arts creative pedagogy: Their role and manifestation

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ABSTRACT

This paper responds to recent calls to explore the nuances of the interaction between the sciences, the arts and their inherent creativity to better understand their potential within teaching and learning. Building on previous arguments that the science-arts-creativity relationship is dialogic and relational, this research focuses on the question: How are dialogue and material/embodied activity manifested within creative pedagogy? We begin with a fusion of Bakhtinian-inspired and New-Materialist understandings of dialogue drawing out the importance of embodiment in order to revitalize how we articulate dialogue within creative educational practice. We then take on the challenge of a materialist diffractive analysis to conduct research which complements the theoretical framing and offers our outcomes in a way that appropriately makes the phenomena tangible. We present the outcomes of the diffractive analysis including the constitution of matter as well as meaning in the dialogic space; and the emergence of new assemblages of embodied teachers, students, ideas, and objects within transdisciplinary educational practice. We conclude by arguing for the benefits of diffractive analysis: that we have fore-fronted the entangled relationality of trans-disciplinary creative pedagogy; avoided bracketing out aspects of education that are often side-lined; opened out the space of pedagogical approaches that might be attempted; and begun to challenge what education is for. In so doing, the article aims to open up new ways for teachers, students and researchers to experience seeing, doing, feeling and researching science|arts creative pedagogy and provoke conversations about how this might develop in the future.

1. Beginning

There is a burgeoning area of practice and research around the shift from STEM (Science, Technology, Engineering and Maths) to STEAM (Science, Technology, Engineering, Arts and Maths) education, including work to understand the relationship between the arts, sciences and creativity (Buck, Sotiriou, & Bogner, 2018; Colucci-Gray et al., 2017). Increasingly arguments have been made for the need to explore the nuances of the interaction between the sciences, the arts and their inherent creativity to better understand

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their potential within teaching and learning (e.g. Medina-Jerez, Dambekalns, & Middleton, 2012; Van Der Veen, 2012). This research responds to these calls, building on our previous arguments that the science-arts-creativity relationship is dialogic (Chappell, 2018; Hetherington & Wegerif, 2018), and that this should be considered within an understanding of education as relational (Biesta, 2004). Specifically, this paper focuses on the role and manifestation of dialogue and materiality/embodiment in science|arts creative pedagogy in order to offer insight into how the sciences and arts can come into relational conversation in education, to further student learning and engagement especially in science. Our question is therefore: How are dialogue and material/embodied activity manifested within creative pedagogy?

We aim to establish and explore the dialogic, material and embodied nature of science|arts creative pedagogy by beginning with a fusion of Bakhtinian-inspired and New-Materialist understandings of dialogue, drawing out the importance of embodiment to revitalize how we articulate dialogue within creative educational practice. Inspired by these New-Materialist understandings, we accept the challenge of using a materialist diffractive analysis to conduct our research and in the later sections of this paper we offer the opportunity to 'zoom in' on our empirical work through an in-depth presentation of a sequence of 'diffractions' of our data. This diffractive approach is vital to complement the theoretical framing and offer our outcomes in a way that appropriately surfaces the phenomena. We shift into this territory with the intention of opening up new ways for teachers, students and researchers to experience seeing, doing, feeling and researching science|arts creative pedagogy and to provoke conversations about potential future developments.

This research was conducted in the context of the CREATIONS project, a large H2020-EU funded programme across 11 countries aiming to develop arts-based creative approaches to engender more engaging science classrooms in the context of the growing STE(A)M education movement. It sits alongside research from our EU CREATIONS colleagues who have investigated questions such as how to monitor students' creativity (Conradty & Bogner, 2018a, 2018b; Thuneberg, Salmi, and Bogner 2018). Underpinning all of our studies was an extensive literature review and workshop process which demonstrated the growing efficacy of creative pedagogy in the enhancement of student creativity and engagement, and a set of eight creative pedagogical features were developed (Chappell, Hetherington, Ruck Keene, Slade, & Cukorova, 2015). These were used to design teaching and learning plans for approximately 100 different science-arts activities across Europe.

The eight features are: Dialogue; Empowerment and Agency; Interdisciplinarity; Possibilities; Risk, Immersion and Play; Ethics and Trusteeship; Balance and Navigation; Individual, Collaborative and Communal activities for Change. The project design reflects the strong commonalities between our theoretical perspectives and the eight features. In order to study creative pedagogy legitimately and in depth we have selected two of the eight features which are core to our ongoing theoretical work and the research question (Dialogue and Interdisciplinarity). We articulate and develop these in the theoretical frame, following presentation of the research context.

2. Contextualising

Much research has been carried out into creativity and creative pedagogies and we make no attempt to cover this all here. This section offers brief information as to the immediate context of creativity and creative pedagogy research in late primary and secondary science education,[1] before the next section offers the focused detail of the theoretical framework specifically developed for this study.

One of the most recent elements of this context is a significant BERA (British Educational Research Association) research commission (Colucci-Gray et al., 2017) which explored inter- and trans-disciplinary work within STEAM (Science, Technology, Engineering, Arts and Maths) education. The report identified a need to clarify terms (e.g. whether the A refers to Art/the Arts more generally) and philosophical values informing curriculum design, particularly relationships between disciplines and their associated knowledge. It highlights the connectedness enabled by STEAM; learners link knowledge and environment, becoming more creatively engaged and responsive to their communities, and teachers make connections with peers and external partners. The CREATIONS Literature Review (Chappell et al., 2015) found that when delivered by skilled teachers, supported by effective training and sustainable, embedded pedagogical transformation transcending short-term partnership (Ben-Horin, 2015), STEAM pedagogies had the potential to be generative and exciting, enabling discussion and access to abstract scientific ideas, and facilitating understanding of pupils' thinking.

2.1. Creativity

Broadly speaking, recent seminal creativity in education research and practice suggests a 'democratic' approach (Banaji, Burn, & Buckingham, 2010), recognizing the everyday creativity of all children, whilst acknowledging that novelty may apply only to the creator/s (Boden, 2004; Craft, 2013; Kaufman & Beghetto, 2009), and this has been influential in defining creativity and creative pedagogy within STEAM studies. The CREATIONS definition of creativity in science education drew on literature reviews of creative pedagogy research, including that mentioned above, and was co-created through international workshops, refining a definition developed in earlier EU-funded science education projects.[2] The final agreed definition was:

Purposive and imaginative activity generating outcomes that are original and valuable in relation to the learner. This occurs

[1] Much fuller information can be found in the CREATIONS Literature Review (Chappell et al., 2015).

[2] Creative Little Scientists (Cremin et al., 2015; http://www.creative-little-scientists.eu) and CREAT-IT (Craft et al., 2014; http://www.creatit-project.eu).

through critical reasoning using the available evidence to generate ideas, explanations and strategies as an individual or community, whilst acknowledging the role of risk and emotions in interdisciplinary contexts.

Cremin and Barnes (2014:467) highlight that 'creative teaching should not be placed in opposition to the teaching of essential knowledge, skills and understanding'. McWilliam (2008) describes a transition from teachers behaving as 'sage on the stage' (one-way transmission from teacher to learner), to 'guide on the side' (supporting learners by engaging alongside them) to 'meddler in the middle' (engaging in the dynamic of learning with learners) and adopting an 'improvisational' approach (Sawyer, 2012). Jeffrey and Craft (2004) distinguish between teaching creatively and teaching *for* creativity (fostering creativity in students within particular disciplinary areas). In teaching creatively, the 'learner inclusive stance' (Jeffrey & Craft, 2004) enables co-participative approaches where children's perspectives help to guide learning. Craft (1998) identified the importance of human connections with pupils and with the self, and the value of professional judgement, critical reflection and adaptability. Kuntz, Presnall, Priola, Tilford, and Ward (2013) identify that most creative pedagogies occur within the classroom, indicating a need to share innovative practices, developing pedagogical creativity within the constraints of state and school driven programmes. Through confidence in their ability to recognise and employ their own creativity, teachers are empowered to offer children 'spaces for emotional and intellectual growth' (Cremin & Barnes, 2014:471), spaces placed under increasing pressure by performative education cultures and the pervading influence of capitalist economics (Glaveneau, Sierra, & Tanggaard, 2015).

2.2. Creative pedagogical approaches to science education

Creative teaching and learning for creativity sit within a wider debate about the purposes of science education. Research suggests a tension between economic imperatives for a scientifically educated and engaged population (Deboer, 2000) and perceptions by school pupils that science is 'not for me' (Archer et al., 2013). Osborne and Collins (2001) highlight the importance of relevance, identity and creativity in engaging students in science, contrasting with a more dogmatic, content driven approach, contributing to perceptions of science as a non-creative endeavour. Creative pedagogical approaches to science education seek to address questions of relevance and pupil agency. Examples include increasing pupil choice regarding contexts for learning (Wegerif, 2011), engaging students in developing critical and creative thinking through dialogue (Yang, Wegerif, & Pifarre, 2013), connecting students with scientists through analysis of real laboratory data to model and develop scientific creativity as fundamental to the nature of science (Kourkoumelis & Vourakis, 2014), and 'playing' with scientific concepts through digital games (Smyrnaiou, Foteini, & Kynigos, 2012).

The CREATIONS features were derived against a background of inter- and trans-disciplinary work and creative pedagogies. We argue that they can be successfully applied if teachers engage in the dynamic of learning with learners, with creative education viewed as a relational act rather than information exchange between teacher and learner. The CREATIONS features, founded in respect for professional wisdom, recognise practitioners' wealth of teaching and disciplinary expertise – a deeply contextualized knowledge, informed by intuition and in dialogue with scientific theories. Within the CREATIONS project, practitioners are seen as wise professionals applying the features of creative education to make scientific learning creative though meaningful engagement in an educational relation (Biesta, 2004).

3. Theoretical framing

Within this context, we have honed in on investigating the role and manifestation of dialogue and materiality/embodiment in science|arts creative pedagogy which emerged as the potent focus of questioning and discussion with our EU colleagues, as well as increasingly arising within our theoretical reading (e.g. Bakhtin, 1984; Barad, 2007; Biesta, 2004; Braidotti, 2013; Wegerif, 2010). In so doing, it must be noted that in contrast to the contextual literature reviewed above this piece of research marks a shift away from more humanly conceived conceptions and definitions of creativity (even the CREATIONS definition which was itself drawn from existing dominantly humanly-focused literature on creativity in science education). Since the beginnings of the CREATIONS project in 2015, our own research work has become increasingly influenced by new materialist theorizing which moves beyond the human (e.g. Barad, 2007; Braidotti, 2013). This shift for us in STEAM education is akin to, for example, Lenz Taguchi, (2009,2011) work using new materialist theories and practices to develop pedagogy within early years education that offers embodied, material approaches for creative and experimental learning, which moves on from previously more humanist-influenced early years research and practice (e.g. Craft, 2002).

We therefore begin our close-up theoretical framework by articulating and developing via new materialist influences the notion of 'Dialogue', as foundational to understanding creative pedagogy in the context of science|arts education.

3.1. Dialogue

We see dialogue, as the driver for learning and creativity, to be fundamental to creative pedagogy. According to Bakhtin, new knowledge is created through dialogic interactions between 'voices' embodied not just in humans but in 'others' – texts, movements, artefacts, experiments; 'I hear voices in everything and dialogic relations among them.' (Bakhtin, Holquist, & Emerson, 1986:169). Wegerif (2010) expands on Baktin's work using the notion of *dialogic space* to conceptualise the shared, relational space that emerges in a dialogue: a space where people are able to switch perspectives and construct each other (or, to use Biesta's (2008) language, a space in which new subjects emerge). Chappell, Craft, Rolfe, and Jobbins (2012), writing about creativity, and also drawing on

Wegerif, describe this as a process of becoming, which offers "potential for new world views" (Bakhtin, as cited in Briginshaw, 2001:18). Creativity, understood as the generation of novel outcomes that are valuable to the learners, is therefore fostered through dialogue as a result of engaging with an 'other' to view the world from a different perspective.

In our theoretical framing of dialogue in the context of creative pedagogy, we take as our starting point the notion of dialogic space and the switch between voices in a dialogue from Bakhtin. Before moving forward, what is voiced in dialogic space, and what or who is doing the 'voicing' requires exact explanation. Taking seriously Bakhtin's point that voices engaged in dialogue are not only human, we recognize the crucial role of the other-than-human 'other' in creative dialogues. Wegerif et al. (2017:2) argue that dialogue includes "background 'things' that are currently treated as dead things that have no voice", highlighting that a simple understanding of dialogue as a conversation between human beings is insufficient: we must pay attention to the animation and participation of the other-than-human voices in dialogue. In developing this within our theoretical framework, we turn to new materialism, in particular the Agential Realism of Karen Barad (2007). For Barad, agency is not a human 'capacity to act' (in the context of creative pedagogy we might think of this as teachers and students feeling able to play with possibilities and take risks). Instead, she reformulates agency as a relational performance enacted intra-actively within an entangled assemblage of material and embodied human[3] and thus this reformulated concept of agency is crucial within her framework to understand the basis of her relational onto-epistemology.

Barad's new materialist stance and Bakhtinian dialogic could be seen as incommensurable as a result of the continuously emergent nature of boundaries between intra-acting objects in Barad's work, compared with a reading of Bakhtin in which the voices pre-exist the dialogue. However, as argued by Hetherington and Wegerif (2018), and also by Carlile, Nicolini, Langley, and Tsoukas (2013) (citing Shotter, 2013) the two strands of thought can be drawn together because both are grounded in a fundamentally relational ontology. For Barad, new phenomena are produced through agential intra-action which changes the entangled, intra-acting elements. Similarly, Dialogic theory derived from Bakhtin holds that "Dialogism assumes that identities are formed out of and within relationships, not the other way around" (Wegerif et al., 2017). Despite these similarities, however, were it the case that intra-action within entangled phenomena meant that *there were no boundaries* then it would indeed mean that Barad's philosophy could not be brought to bear within a dialogic understanding of creativity since dialogue requires the existence of an 'other'. To address this question, we need to draw on Barad's concept of *agential separability*. This refers to the dynamic process by which temporarily boundaried phenomena are produced through intra-actions that enact agential cuts. For Barad, everything is entangled, meaning that objects, or 'things' cannot pre-exist their intra-action but are constantly produced by and are productive of each other *by means of* their intra-action. As Carlile et al. (2013:10) citing Shotter (2013) put it, "'things'…are not already made, independently existing entities, but always in the making, existing as dynamic stabilities forming ever-changing relations". Thus, dialogue is possible between these temporarily bounded, temporarily 'othered', agentially intra-active entities.

Having argued that Barad's Agential Realism and Bakhtin's dialogic are theoretical strands that can reasonably be woven together, we now return to explore the implications of agential realist new materialism for our theoretical framing of dialogue within creative pedagogy. The key to this is in Barad's assertion that 'matter comes to matter' within her theory: it provides a means by which the agency – the voice – of the material can be understood as an active participant within the dialogue rather than an inert backdrop or a voice animated within the dialogue only by human activity. It requires us to pay attention to the way in which material bodies participate in the dialogue and pushes us to notice the voices of assemblages or groupings of human and other-than-human participants in dialogue, where the boundaries of those groups are dynamic and can shift, dissolve and be remade as learning proceeds.

This means that we can consider nature, technology, science and arts tools as active 'players' that can change the conversation of creative pedagogy because they contain the potential for new possibilities beyond the human (Chappell, 2018). This understanding is derived from Braidotti (2013:107) who in relation to, for example, art, drawing on Deleuze states that we are transposed "beyond the confines of bound identities" and that "art becomes necessarily inhuman in the sense of nonhuman in that it connects to the animal, vegetable, earthy, planetary forces that surround us". Returning to the idea of dialogue as fundamental to creative pedagogy and creativity, if it is more equally enacted between human and other-than-human players, a dialogue between materially embodied other living forms, objects and humans allows more perspectives into the creative process and pedagogy, leading to a richer set of possible new educational ideas because of the inclusion of more sources of action.

In exploring dialogue with and through agential realism, we can begin to see how the two theories can productively be related to – or intra-acted with – each other. One further intra-action between these two theoretical strands offers a useful perspective on the spatiality of embodied, material dialogue. The spatiality of dialogue was previously considered by Chappell and Craft (2011) in their discussion of 'Living Dialogic Space', arguing that creative pedagogy must also, of necessity, allow for the production of living, dialogic space. Terming dialogic space as 'living' highlights its fluid and dynamic nature, but in line with the theoretical inclusion of material voices in the dialogue, we can further draw on Barad's work on entanglement to re-think the materiality of living dialogic space and its implications for creative pedagogies. At the heart of Barad's work are entanglements: "To be entangled is not simply to be intertwined with another, as in the joining of separate entities, but to lack an independent, self-contained existence" (Barad, 2007, loc 19). Everything is entangled, with matter and meaning always produced through relations, not between pre-existing separate entities, but between phenomena that continually 'co-emerge through their simultaneous activity' (Rautio, 2013, p. 2). Given that these intra-actions between entangled, temporarily boundaried phenomena are material intra-actions, 'dialogic space' must be more than a conceptual space of disembodied ideas in relation, and more than a living space of dynamic interaction between bodies: it must be a space of intra-active material relationships of entangled matter and meaning (Hetherington, Noakes, Hardman and Wegerif,

[3] Note Barad's term intra-action rather than interaction denotes that boundaries between entities are continually produced in the intra-action.

under review). Such a conceptualisation of a material, or embodied, living dialogic space has implications for creative pedagogy. Meaning created within dialogic space may be materialized (as Barad might put it, may 'come to matter') in classroom practice in distinctive ways if, for example, the artefacts, bodies, and disciplinary voices of the arts and sciences are drawn together in a creative pedagogical approach.

Thus, if we are to engage science students through the arts in projects like CREATIONS, we argue that we need to do so through embodied dialogic spatial pedagogies that recognize the material and fluid nature of both the sciences and the arts and those engaged in them. It is this articulation of pedagogy that we endeavor to explore in this paper. The notion of entanglement within an embodied living dialogic space is an important aspect of this pedagogical approach, since an intra-active framing of dialogue concerns relations between *entangled* phenomena. This has implications for the next key feature in our theoretical framework: transdisciplinarity.

3.2. Transdisciplinarity

Increasingly our theoretical perspective has shifted from articulating the relationship between the arts and sciences as inter-disciplinary (the original name of the CREATIONS feature) to articulating it as transdisciplinary. Lattuca (2001) describes trans-disciplinarity as: "the application of theories, concepts, or methods across disciplines with the intent of developing an overarching synthesis" (Guyotte, Sochacka, Costantino, Walther, & Kellam, 2014:83). In line with Colucci-Gray et al. (2017), and our diffractive perspective, we go beyond synthesis to adopt Morgan's understanding of transdisciplinarity: "My operating style is to incorporate reliable sources of knowledge from any source, as it bears on the point I am trying to make" (Morgan, 2000:39), or as we see it 'as it bears on the question I'm trying to ask'. We see transdisciplinarity as rooted in asking questions beyond disciplines and (particularly in educational contexts) fuelled by students' and teachers' curiosity. It is in response to curious questions in education that trans-disciplinarity emerges. As Colucci-Gray et al. (2017) state, citing the First World Congress of Transdisciplinarity (1994, Article 3):

> Transdisciplinarity complements disciplinary approaches. It occasions the emergence of new data and new interactions from out of the encounter between disciplines. It offers us a new vision of nature and reality. Transdisciplinarity does not strive for mastery of several disciplines but aims to open all disciplines to that which they share and to that which lies beyond them.

This transdisciplinary perspective ties to our developing relational ontology, in which the intra-action of 'others' produces emergent outcomes: difference is creative. It is important to allow that transdisciplinarity is not just one approach but is open to include disciplinary combinations responding to non-disciplinarily driven questions, to include syntheses, and embrace openness to what lies beyond disciplines.

3.3. Synthesis

This theoretical frame offers two key features of creative pedagogy: dialogue and inter/transdisciplinarity. Central to this frame is the notion of embodied living dialogic space – a shared, relational, creative, material space, that is produced by dialogue between 'others' (humans and other-than-humans) and is productive of subjectivities or identities as well as ideas. These dialogic spaces are fluid and dynamic spaces of possibility. Enmeshed with this, transdisciplinarity is vital both to embedding CREATIONS teaching and learning activities with a nuanced and open-ended relationship between the arts and sciences; and as the context within which we ask the research question: How are dialogue and material/embodied activity manifested within creative pedagogy?

4. Methodology

Our theoretical stance suggests a methodological approach enabling a creative response to the dynamic settings of Arts|Science practices we are researching. This has led us to a diffractive methodology (Barad, 2007; Haraway, 1997) drawing on multiple methods within a responsive research design. In Physics, diffraction is 'the spreading out of waves as they pass through an aperture or around objects' (*Isaac Physics*, 2017). Barad (2007), building on Haraway (1997), develops diffraction as a methodology, highlighting how different methodological 'cuts' interrupt, bend and diverge the object of study in co-productive ways creating the object/s, data and methods together. The term 'cutting together-apart (one move)' (Barad, 2014) describes this process. Diffractive methodology is essentially performative (Van der Tuin, 2011): in empirical work,[4] assemblages are made up of elements intra-acting to 'do something, to produce something' (Fox & Alldred, 2013:403). In our diffractive process, research assemblages were created in response to questions, making particular methodological cuts, creating new knowledge and new questions to which we responded with the development of a new research-assemblage in a series of diffractions.

In researching inherently dynamic, open-ended creative pedagogies, methodologies that seek closure are, we suggest, insufficient to the task as they do not acknowledge the complexity of the focus of the study (Uprichard & Dawney, 2016). Diffractive methodology responds to this challenge, making explicit the process of production of new insights through creative, diffractive, entangled dialogue between researchers, questions, methods, data and objects of study.

[4] In contrast with diffractive methodology employed with respect to texts

Table 1
Details of cases.

Case	Context	Sample	Activity	Data collection methods
Arts/Science Action Research	7 Science/Art teacher pairs in 6 UK Secondary settings connected to University of Exeter (UoE)	2 Science teachers, 2 Arts teachers, and 24 pupils	Action research by teachers investigating arts-based creative approaches to promote engagement with science (2–6 weeks). Site 1–4 activities Site 2–1 activity	Before and after pupil conceptual drawings of science and art education, fieldnotes, video, interviews and photographs.
Global Science Opera	2 arts educators and one scientist, 3 research assistants collecting data in one Norwegian high school.	12 students and one (drama) teacher.	3 day workshop at one high school combining lecture and practical. Arts workshop to develop opera, "One Ocean".	Reflections, observations, photographs, interviews with drama teacher, post-questionnaires.
Art and Science at School	4 month project as part of Visual Arts module of IB course for Greek high school students.	2 Art teachers, 1 Physics teacher, 24 students.	Students develop art works inspired by Particle Physics and CERN.	Semi-structured interviews – students and teachers, student mind maps, reflections, photographs of art works.
Particle Dance	1 day workshop – particle physics in the dance classroom. Two dancers and a musician, particle physicist from University of Birmingham (UoB).	1 art teacher and 15 students.	Students discuss fundamental constituents of matter and their interactions and create a sequence of dance moves and choreography of particle interaction	Before and after student drawings of creativity in science, field-notes, photographs and video, interviews. post-questionnaires.

4.1. Designing the research

The research used a multiple case study design within a diffractive methodology. Case study focuses on particular cases of relevance to the area of interest (Chadderton & Torrance, 2011). We draw on four cases (see Table 1) where the CREATIONS features were used to develop distinctive creative science|arts pedagogies.

Within our diffractive methodology, multiple methods were appropriate due to the multi-dimensional, complex and entangled nature of the area of study (Uprichard & Dawney, 2016). These were combined dynamically to be responsive to our emergent learning. Methods included semi-structured interviews with 52 pupils and 10 teachers (Galletta, 2013), field observations of activities (Yin, 2003), photographs (Kara, 2015) small-scale surveys, physical artefacts produced, and teacher logs, and were complemented by post-activity questionnaires (reported elsewhere in project deliverables), exploring motivation and creativity. Protocols for qualitative data collection prompted attention to material and embodied interaction alongside 'talk'. Data was collected in participants' first language and translated into English where necessary. Analytical discussions were in English. Images representing the diffractive process have been included within the text to document and bring alive our discussions; close reading of any written text within the images is not necessary as where close textual analysis is central to understanding, the relevant language has been considered within the flow of the discussion, or is visible within the images.

4.2. Approaching analysis

'Diffractive analysis' focuses on the emergence of new phenomena through relationality and difference. Previously published diffractive analyses have engaged with data by reading it diffractively through multiple theoretical lenses (Mazzei, 2014), or by focusing and refocusing on intra-action of different data elements to move away from anthropocentric approaches (Lenz-Taguchi, 2010). Diffractive analysis directs attention to the agentic role of both theory and material in research alongside the human 'subject'.

Employing diffractive analysis across multiple international cases and a large data set is a novel approach. It is therefore important to clarify the rigour and legitimacy of the responsive design. Within this new approach rigour cannot derive from matching case size or type, since in contrast to more usual qualitative approaches to comparative Case Study (such as thematic analysis), diffractive analysis focuses on the juxtaposition of difference and how it makes a difference. We therefore needed to work from a different standpoint in our efforts to ensure the rigour and legitimacy of the study (Ulmer, 2017). Learning from other new materialist empirical studies (e.g. Somerville, 2016), we therefore evolved an analytical approach that maintained rigour through meticulous documentation of the processes, tracing-and-mapping the intra-actions between data, theory and questioning. Tracing-and-mapping involves "extracting events, problems and concepts from the chaos of multiple realities…[and] setting up and creating new events, possibilities, problems and concepts" (Lenz Taguchi, 2016). For example, rather than use inter-coder reliability to seek similarity and saturation (Silverman, 2015), differences between analysts become a traced and acknowledged part of the data diffracting through the analysis; prompting questions, reaching interim conclusions, and developing theory across multiple iterations. The legitimacy of this process arises from the synergy between questions, theoretical framework, design and analysis (Onwuegbuzie & Johnson, 2006).

The primary unit of analysis in our process is the 'assemblage' (Fox & Alldred, 2015), composed of selected data. A new materialist perspective on data selection suggests that it is not the human alone who chooses which data to include, but the agentic intra-action of data and researcher/s together. We therefore refer both to assemblages of data, and researcher-data assemblages who perform the analysis. MacLure (2013), drawing on Deleuze and Guattari, refers to 'moments that glow', a term we use to describe data that pushed itself forward into the assemblages, standing out as intriguing, exciting, disturbing and challenging (a photograph of a fish on a lab table, a poem produced by a student, a quote from teachers about the challenges of balancing creative pedagogies with curriculum…). We engaged in a sequence of diffractive analyses in which different researcher-data assemblages were constructed in response to a question drawn from theory (and) previous diffractions, zooming in and out of interim conclusions and new questions. This process is described in detail as we present each diffraction below, beginning with brief discussion of the early diffractions and then focusing in greater depth on two key diffractive responses to our ongoing questioning of the data. In a sense, the remainder of the paper presents methodology, analysis and discussion as one narrative piece since the description of the diffractive analysis offers insight into the methodological process as well as the substantive analysis of data/theory together. In diffractive terms, we imagined the questions driven by our theoretical framework as analogous to 'slits' which cause interference and result in distinct diffraction patterns; we also noted through the process that the different actors in the assemblages also acted as 'diffraction gratings' (see Fig. 1).

Thus, the process did not strive for closure, a 'right answer' or a representation of a concept (as might be the case with theoretically-driven coding), but instead used questioning to 'interrupt' our habits of thinking, deriving questions to 'weave data into theory into data' (Mazzei, 2014:743). In engaging in this diffractive analytical process, researchers, theory and data together produce agential cuts that generate new knowledge and new questions, meaning that the specific research process and its outcome is unique to this assemblage of cases, traced below as a sequence of diffractions. Data analysis was conducted by those researchers most closely involved with the data: Kerry, Lindsay, Heather, Hermione, Oded, Janne, Kostas and Angelos (see biographies in Appendix 1).

4.3. Ethics

An ethical approach to research drawing on a relational ontology in diffractive analysis requires a dynamic ethical *process*, acknowledging that in choosing to attend to some data and not others, for example, some voices are excluded whilst others are included. Our ethical stance moved beyond simple procedures of informed consent, participant anonymity, safeguarding of children with respect to the use of video, and safe data storage (although these were attended to using each researcher's appropriate University

Fig. 1. Wave Diffraction.

ethical guidelines, BERA guidelines (BERA, 2018) and EU Responsible research and innovation procedures. We engaged in responsive ethical thinking, documenting our decision making when ethical questions arose, for example around the 'loss' or 'silencing' of some voices through the selection of the 'glow moments'.

5. Diffracting

5.1. Diffraction 1

Heather worked with the data to produce data assemblages before the analytic group met together (Kerry, Heather, Lindsay and Oded face to face with Kostas, Hermione and Angelos on Skype). Discussion of concepts rooted in prior reading of five extracts from key texts drawn from the theoretical framework (Barad, 2014; Biesta, 2004; Hetherington & Wegerif, 2018; Todd, 2016; Wegerif, 2007) led to questions with which to diffract the data (see post-it notes, Fig. 2 a). Researcher-data assemblages were formed with three/four researchers and two data-assemblages in each. The diffractive material-dialogue was mapped collaboratively (Fig. 2) and videoed, documenting and developing insights as theory, data and researchers made agential cuts 'together-apart'. At the end of this process, two analytic questions stood out as questions that 'glowed':

1. What happens in that moment of entanglement (between disciplines)? (connected to Barad, 2007)
2. How is dialogue used as part of meaning-making in the gap/dialogic space? (both human and non-human) (connected to Wegerif, 2014).

5.2. Diffraction 2

To explore the different cases using the questions generated in our first diffraction, analysts from each country explored assemblages of their own case using the two questions (Fig. 3). That diffraction produces distinctive, different emergent outcomes is clear, as although each researcher-data assemblage worked with the same questions, the outcomes look very different. The diffraction developed a multiplicity of thoughts around each analytic question, for example around meaning-making within embodied dialogue about the situated nature of dialogue in and with space and time. It also foregrounded the co-production of methodological processes by researcher and data, prompting new ideas for further diffractive processes.

Having focused in diffraction 2 on individual cases, we then moved to exploring the cases together. New data assemblages were generated by an analyst from each country selecting up to 8 glow moments (GMs) from their case, responding to diffraction 2. This researcher-data assemblage then together (via Skype) selected 12 GMs from across the case-based GM assemblages to produce a cross-case GM assemblage (Appendix 2), before proceeding with diffractive analysis of the new assemblage in response to the analytic questions.

The data was selected from each country's project. In the UoE driven UK sites this included photographs of artefacts, work environment and students' learning; student and teacher quotations from interviews and conversations with the research assistant; student drawings of their perceptions of creativity and science; planning notes and drawings from students; and artefacts from an art activity based on 'big ideas' in science and a 'Wild' project which merged dance and art with explorations in the local outdoor environment. In Norway, interview (quotes), written responses to questions; reflection notes by three Masters students who had roles as research assistants, and a visiting scientist; images/pictures of work environment; artefacts and the script written by the pupils were gathered from an activity focusing on developing a storyline for the 2018 Global Science Opera ("One Ocean") with the scientific theme of marine life and the importance of focusing on sustainability. In the UoB UK site student and teacher quotations from interviews and conversations; student drawings of their perceptions of creativity and learning about particle physics; and photographs of the learning environment were taken from an activity which used dance to teach young students about particle physics. In the Swiss site transcribed semi-structured interviews and conversations with students and teachers were undertaken by the

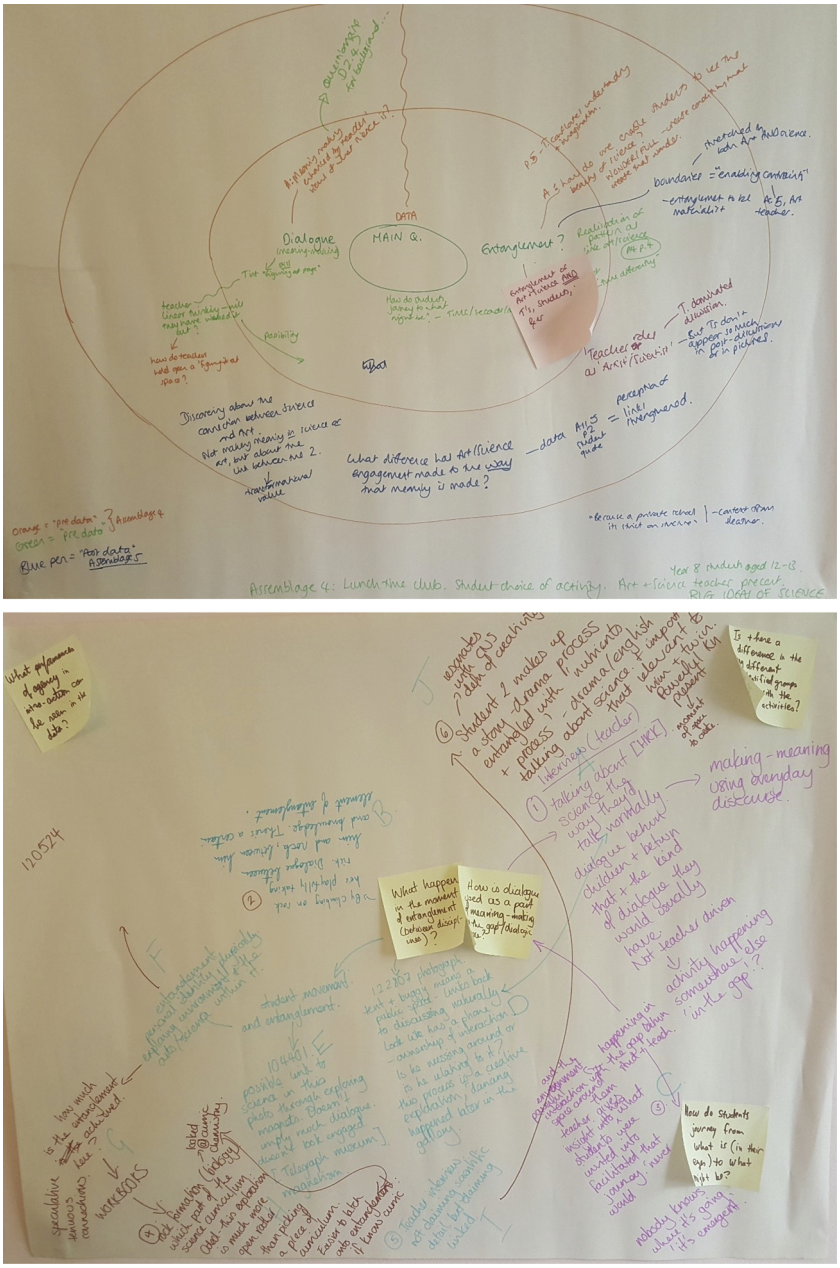

Fig. 2. Diffraction maps.

research assistant. Additional data was obtained in the form of mind maps that students were asked to design in order to reflect on their experience by specifically placing themselves in dialogue with their artworks and their capacity to be creative in science activities. The data at this site was generated from students and teachers involved in a science and visual arts International Baccalaureate (IB) school project in collaboration with the art@CMS initiative at the CMS experiment at CERN. The project asked students to design and create artworks and artefacts inspired by particle physics and CERN that would form part of their IB art portfolio.

The Glow moments from each site were identified due to their capacity to exemplify central issues related to the research questions, their ability to “speak for themselves”, and their ability to provide information/impressions which the researchers hadn’t necessarily considered in advance.

5.3. Diffraction 3

The analytic question ‘What happens in the moment of entanglement (between disciplines) was used to diffract the cross-case GM

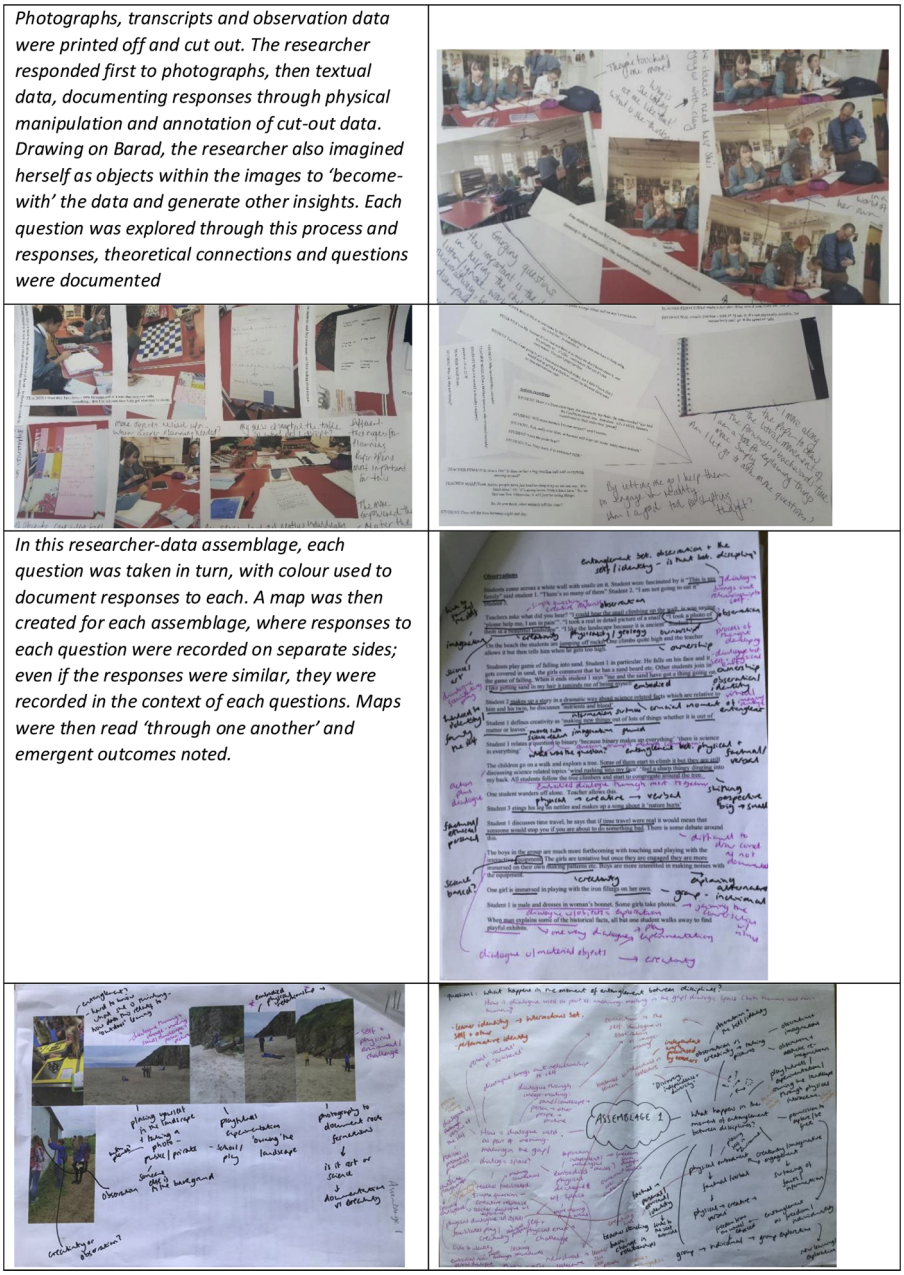

Fig. 3. Examples of diffraction 2 maps.

data assemblage, initially with each analyst-data assemblage literally 'cutting together-apart' the GM assemblage to produce a collage (see Fig. 4 for examples).

Photographs of these collages were shared and a researchers-collages assemblage formed via Skype, in which insights from theory and data were read through one another, enmeshing data, theory, questions and insights together creatively to gain insights and prompt new questions. Emerging questions related to the entanglement of identity, difference, confusion, emotions and beauty and a broader notion of entanglement. This diffractive dialogue was recorded for further analysis.

5.4. Diffraction 4

Following immediately from diffraction 3, in diffraction 4 the researchers-GM assemblage worked with the analytic question 'How is dialogue used as part of meaning-making?'. 2 GMs were randomly selected and discussed together with the dialogic theory drawn from our theoretical framework for creativity. This process was conducted three times, voice recorded and transcribed (GM

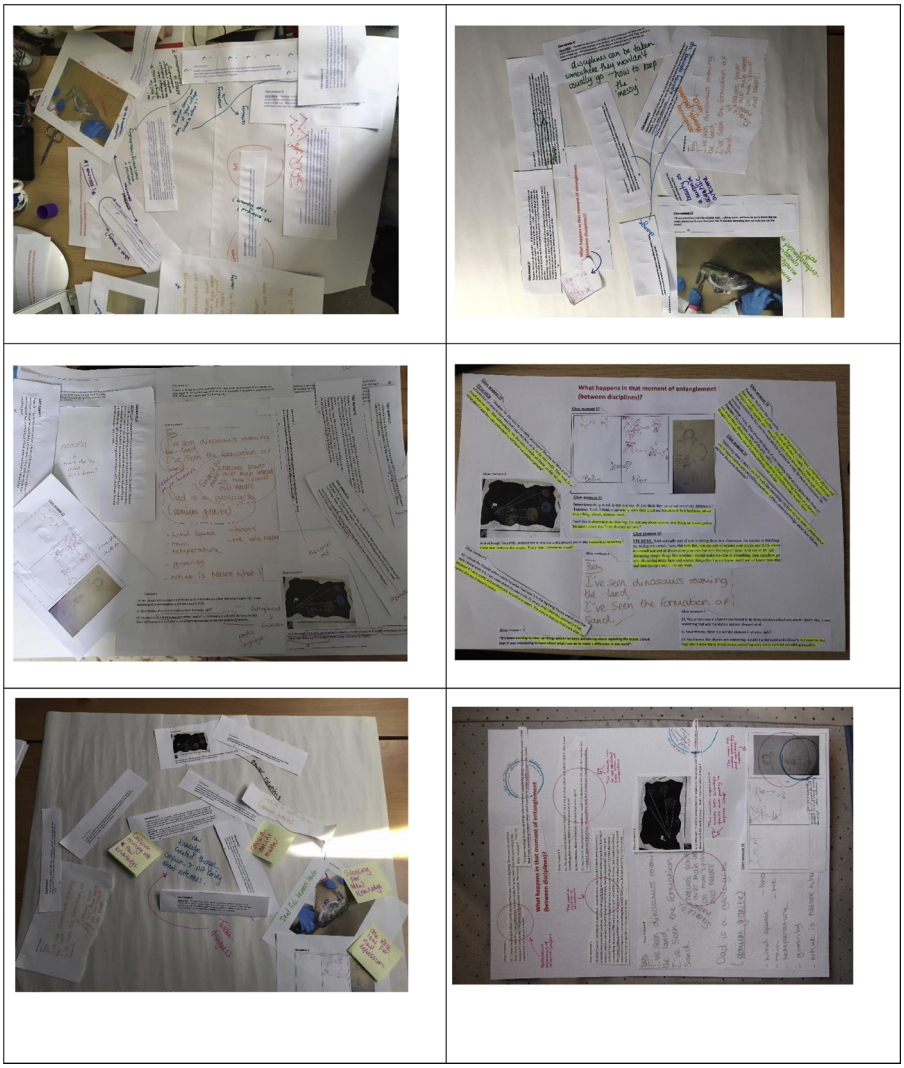

Fig. 4. Diffraction 3 collages.

pairs discussed shown in Fig. 5). The first GM emerged from a student quotation referring to their learning gathered from the learner group interviews relating to the Norwegian "One Ocean" project which focused on sustainability, and the second GM was formed using student drawings which expressed their learning relating to creativity and science before and after the UK 'big ideas' project. A

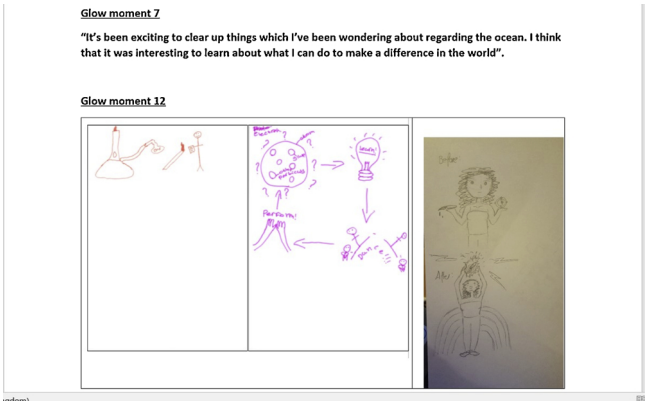

Fig. 5. Glow moment pairs.

set of two student's images were chosen for this GM because they emerged as belonging together as they represented science and art in interesting ways. Arising questions related to the colonization of art and science in schools, affect and difference, confusion and the importance of students understanding the subject.

5.5. Diffraction 5

An assemblage of Kerry-Lindsay-entanglement transcript-collages-audio was formed to explore in more depth the emerging insights and developing questions in relation to the 'entanglement' analytic question, first through discussion and then through a dialogic writing format, leading to the first part of the writing in the 'Two Diffractions in detail' section below.

5.6. Diffraction 6

An assemblage Hermione-Heather-Janne-Oded-Kostas-Angelose-GM pairs worked with the analytic question about meaning-making through dialogue. They engaged in further 'dialogue with the data', building on diffraction 4. The assemblage Heather-Hermione-D4dialoguetranscript-GM pairs then created a collation of questions, comments and concepts to which Janne, Oded, Kostas and Angelos responded in writing, adding theoretical questions and emerging questions, leading to the writing in the second part of the 'Two Diffractions in detail' section below.

Through this sequence of six 'diffractions' of the data, new insights and questions emerge that, though unique to this research, push us to rethink creative science l arts pedagogy. These insights are explained and explored through the discussion in the next sections, drawing primarily on diffractions 5 and 6. However, it should be clear that the insights emerging in these final diffractive analyses are enabled and constrained by the preceding diffractive analyses and are an outcome of the whole process.

6. Two diffractions in detail

6.1. Diffraction 5

In continuing to respond to the question What happens in the moment of entanglement between disciplines? we (Lindsay and Kerry) are aiming to write rhizomatically, in a "form that leads in different directions and keeps analysis and knowledge production on the move" (Mazzei, 2014:743), and so…

Lindsay:

> *…and also GM1 [which emerged from a student interview about the drawing they had created representing their learning before and after the UK 'Wild' project] where it says me dancing, and learning about plants, and doing an investigation, that's really separate…and then the one at the bottom is about pulling it all together, so she's saying, 'I can see uniting these two fields via this project. Hermione, Analysis meeting 21.5.18.*

Both separate *and* together. In entangling the disciplines, in our data we saw that across the projects science and art were brought together whilst also maintaining separation in order to work effectively within creative pedagogy. The 'glow moments' include separate disciplines (see Fig. 6) and a host of different things happening in the relations between them, to do with people, processes, emotions, materials. Barad's 'cutting together-apart' comes to mind (Barad, 2007, 2014). I wonder whether that analytical term is also relatable to what is happening in disciplinary entanglement within creative pedagogy? Barad's perspective would suggest that in intra-action between entangled disciplines, the disciplinary boundaries are continually made: the *meaning* of 'Science' or 'Art' is created through the intra-action. We initially thought about a tangled ball of wool with separate strands and knots, but this is too static. Inspired by the rhizomatics of Deleuzo-Guattarian new materialist scholars (Gough, 2004), is the image of intertwining tree/s more appropriate, with roots and branches that grow together-apart (see Fig. 7)?

Key to this together/apart relationship between entangled disciplines in our analysis is the importance of 'otherness', depicted by the two separate trees, growing together but maintaining their distinct natures. The concept of the 'other' relates to dialogue as the theoretical strand of our conceptualization of creativity (Chappell & Craft, 2011). Within dialogic theory, the 'other' is crucial, otherwise there is no dialogue. Thus, in entangling the disciplines, the 'other' discipline has to be separate, at some point, in order for something new to emerge from the dialogic space between disciplines (Wegerif, 2007).

Kerry: And why entanglement in our question? We chose this term following Barad (2007) to diffractively read data through theory (rather than representing codes and patterns). Barad (2007) is clear that entanglement is not simply intertwining, but implies a lack of independence – with objects, processes and people emerging through their very entanglement. This takes us beyond our Theoretical Frame use of Morgan (2000)'s trans-disciplinarity definition of incorporating knowledge from any source (discipline?) as it bears on the question being asked, and begins to delve within the *entanglement* of arts-science in CREATIONS activity. Part of GM12, the drawing of the girl holding science and art materials separately and then bringing them together in an entanglement over her head generating electricity and a rainbow, brings this idea to life through a student's penciled experiences. It featured in 3 of our analytic collages (Fig. 8).

This glow moment, along with the content of others (see Appendix 2): the fish (GM6 – a dead fish selected for discussion and hands on investigation in relation to biology during the session in the 'One Ocean' project in Norway – which students went on to cook, eat and make opera about), the dinosaurs that the student had seen roaming the land (GM8 – a poem written by a student when thinking about ideas to use in the UK 'Wild' project) and learning particles through dance (the activity of expressing particles through

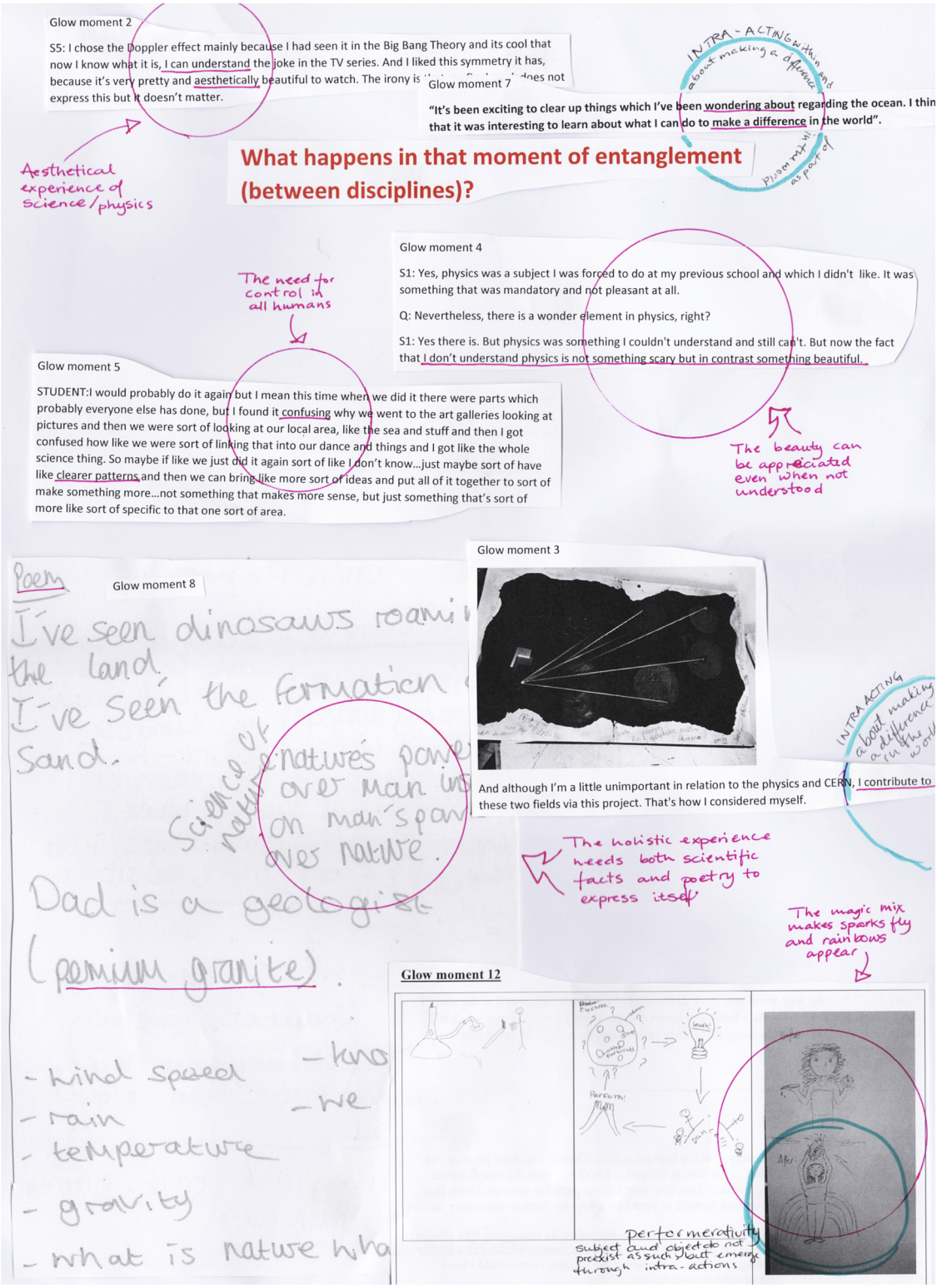

Fig. 6. Example of a collage from the 'entanglement question'.

Fig. 7. Intertwining trees (Gemel Tree Alex Cameron, CC BY-SA 2.0, https://commons.wikimedia.org/w/index.php?curid = 9267058).

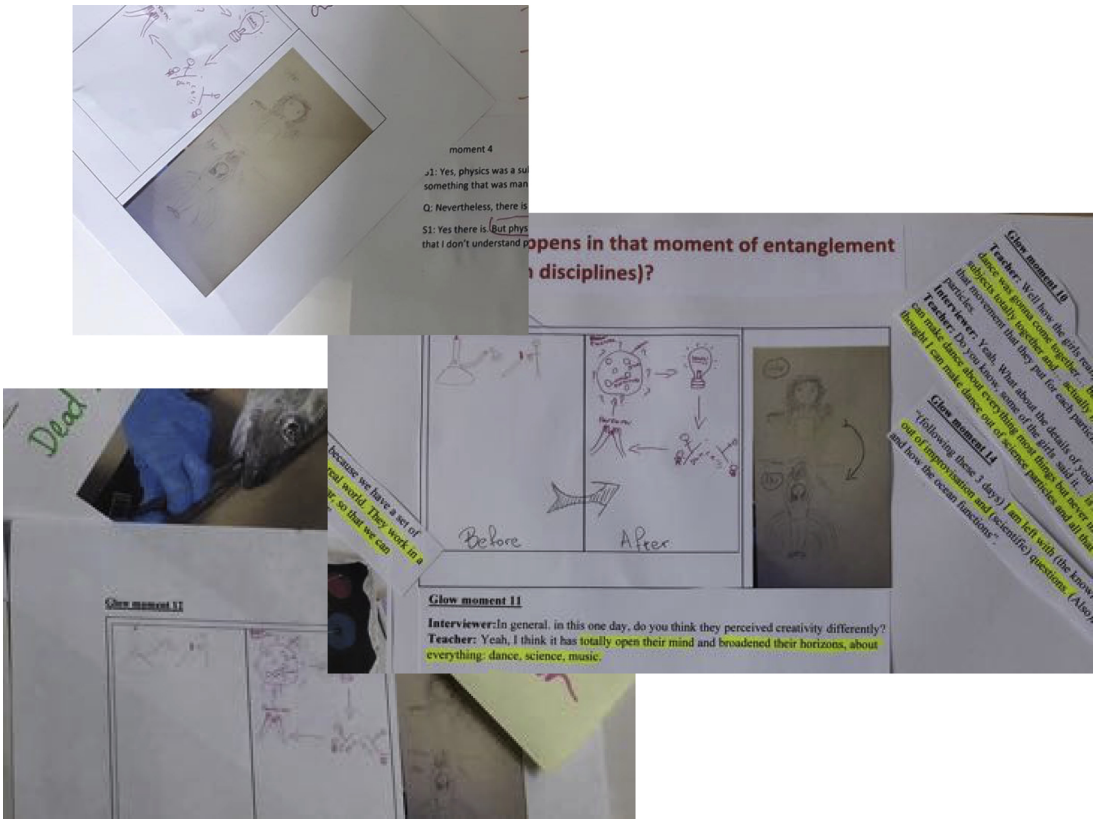

Fig. 8. Snapshots from different collages of GM12.

the use of dance moves relating to the comments in GM10), if again read through Barad's (2007) theory forefronts the importance of materiality within entanglement. A fish inspiring students and facilitators and literally ingested by them; a prehistoric creature 'seen' on the English coast in a poem; atomic physics embodied in students' physicality; a paint brush and an atom penciled into a drawn lightning explosion.

The materiality of human bodies, art works (poems and drawings), other-than-human bodies can be understood as part of disciplinary entanglement: knowledge, rules, skills and processes incorporated and interwoven into students very beings and entangled in 'becomings' (Barad, 2003). These are "particular material reconfigurings of the world with shifting boundaries and properties that stabilise and destabilise along with specific material changes in what it means to be human" (Barad, 2003:818). To reflect the growing plurality of players and their materiality in this conversation (in line with Mazzei's [2014] encouragement to keep knowledge production on the move), we are now developing our analytic question to: *What happens in the momentS of entanglementS between disciplines, humans, and other-than-humans?*

[A further question, which will return in Diffraction 7, is What is the role or fit–or indeed misfit – of this kind of entangled transdisciplinarity in current education systems?]

Lindsay: This brings me back to a phrase of Kerry's, from our analytic discussion: 'Stretchy entanglements':

Fig. 9. Dynamic flow of paints in water.

…might we not be thinking about entanglement as a broader notion…, that [HW] was talking about entanglement in terms of different actants in the process. We've also talked about our own entanglement [in the analysis]…about entanglement within the discipline. But sort of almost getting quite stretchy with the entanglement notion.

For me, this raised the question, 'what is the relationship between entanglement, diffractive analysis and creativity'? As we analysed, the breadth of entanglement we were thinking with shifted, including entanglement between science|art but also with-and-between pupils, teachers, researchers, materials, environments, emotions and concepts.

Although we have not formally articulated it as such, what we seem to be doing in this diffractive process is similar to the notion of 'Concept-as-method', tracing-and-mapping the *concept* of entanglement (Lenz Taguchi, 2016) with/in our data-researchers assemblage. As our questions, processes, responses and further questions, stimulated by the researcher-data assemblage, developed in unexpected ways, so our concept of entanglement continues to emerge and the tools we use to think about it develop. We could use the influential image of the rhizome (Deleuze & Guattari, 1987), but this seems insufficient to show the *differences* between the entangled disciplines-students-materials-teachers. We need a new image: rather than stretchy entanglements, we might shift to fluid entanglements, where different fluids flow together, through and around each other, with ripples, eddy currents, turbulence or laminar flow (Fig. 9).

Kerry: If we now consider this notion of becomings within fluid entanglements, two of Hermione's comments from our analytic discussion are pertinent. She discussed GM2 (a student's comment about how their drawing related to things they had seen and experienced in the real world but that their work in the project did not relate to) as being extremely important in relation to the personal: 'it was very powerful in terms of the…personal, integrating your own life with it'. Later, referring to GM5 (a student interview comment explaining what they had learned from the 'Wild' project) she says 'they were talking about how they were taking what they'd learnt from that process and developing it again, being able to see and empowered to do it'. Her analysis of GM2 articulates the importance of learners and teachers bringing their own life and their curiosities into their becomings within the entanglement and in the GM5 analysis Hermione describes a cyclical becoming of both idea and actant (in this case human). This is perhaps what Barad (2007) means when she discusses *phenomena as becoming* neither as individual entities or mental impressions, but as an intertwining of both. Lindsay and Janne also coupled the personal and the moment of disciplinary entanglement with the role of emotions and feelings (referred to in relation to touch and expression). Lindsay particularly referred to these as being 'underneath what happens in that moment of entanglement'.

Tentatively this reference to feelings of different sorts might connect to what Reid (1980) called 'knowing this' or 'felt knowledge', of direct experience. This is related to aesthetic knowledge but is not specific to arts or sciences. It is a way of knowing that Reid argues needs to be educated for alongside Ryle's (1949) 'knowing that' (propositional knowledge) and 'knowing how' (procedural knowledge). It is not reduceable to these two; it is conscious, immediate, intuitive, experiential, qualitative, in the moment knowledge; it is related to felt emotions but it is not these.

[A second question arises for further consideration in Diffraction 7 – in these glow moments and our diffractive analyses of them we see a hint at the importance to disciplinary entanglements of becoming, the embodied and felt/material knowledge – but how might further investigation of this embodied, felt/material, 'knowing this' of actants help us to work with fluid entanglements? What does it mean to ask about the 'felt' knowledge of other-than-human actants?]

6.2. Diffraction 6

We (Hermione, Heather, Kostas, Oded, Janne and Angelos) continued to consider how dialogue is used as part of meaning-making in the gap or dialogic space through 'dialogue with the data'. We aimed to 'ask not answer questions'. Lindsay described dialogue as

questions leading to answers leading to questions leading.. meaning is always understood in context, so there isn't a correct meaning within dialogue…it's a shared enquiry process … often seen as a way to change either self-reality or social reality. (2nd discussion)

Dialogue was used to make meaning about the data itself, changing the 'self-reality' of the researchers in the process, and interrogating how students and teachers use dialogue themselves to make meaning.

At each stage, different researchers participated in the discussion, leading to a dialogue encompassing Bakhtin and Holquist's (1981) conception of the dialogic imagination and, as Janne said, reminiscent of

> *situations in improvised arts … dependent on the dialogue happening in the here and now in order to create whatever it is you're creating… you would never have created whatever you did … had the other person with whom you're having dialogue not done what he or she did at that moment. (2nd discussion)*

These changing groups, in Kostas' words, comprised researchers of 'different experience and skills', which offers new positions for the speakers which can lead to new possibilities (Wegerif, 2007) and thus

> *…gave the opportunity to shine a light on the topic from many different angles. This generated different reactions to the analysers, which subsequently resulted to unexpected insights in the data – ones that were not anticipated. It is indeed a diffractive process, where beyond letting the data unveil their own story, did actually change (to various extents) the way the analysers think. In modern physics, diffraction occurs when a particle passes an obstacle through different slits, and results – by constructive and destructive interferences – to very interesting – and insightful – patterns. It seems that our different backgrounds correspond to the different slits. (post-discussion document, Kostas)*

As well as changing shape with each group of discussants, each stage of the dialogic process led to further questions. In reporting these discussions, we have used Figs. 10–12 to represent the dialogue that took place in three stages: Stage 1 – The paired glow moments in dialogue with one another and with dialogic theory 'plugged in' – appears on the left of the page; Stage 2 – The group dialogue about the 'glow moments' enactment in relation to the question – appears on the right; Stage 3–The theoretical dialogue and emerging questions about Stages 1 and 2 – appears in the speech bubbles in the centre of the two columns. The speech bubbles in Fig. 10 have intentionally been left blank, to allow readers to formulate their own responses to the 'data in dialogue' before viewing the responses of the dialogic research partners. Following these Figures, a short discussion leads to further questions.

Following this process of 'data in dialogue', 'question-like' aspects of the discussion were pulled out, to maintain the idea of dialogue as 'question leading to answer leading to question'. In some cases, these questions have already been addressed in the wider literature or in previous research projects. For example, in the initial discussion, where glow moments were randomly placed in dialogue with one another, the image in GM12 provoked the thought that 'the gap in between is possibilities, though, isn't it?' (First discussion). This notion of the dialogic space as being fundamental to meaning-making has been well explored in literature (Pifarre & Staarman, 2011; Wegerif, 2007): finding it visually represented here by a student indicated the value of exploiting this dialogic space in pedagogical activities. As Janne and Oded reflected,

> *In between these two excerpts in dialogue, there is a gap. We are not sure we are currently able to define that gap in words, but it relates to possibilities of considering how 'matter and meaning are mutually constituted' in the production of knowledge (Taguchi, 2012): I need tools to help me reach that goal. (post-discussion document, Janne and Oded).*

A further question that arose concerned the natures of the disciplines we are studying

> '*In the end, is school art art, and school science science? Do they have the essential elements to actually be part of the respective disciplines in their completeness?*
> *(post-discussion document, Kostas)*

Again, this is a question that has been explored in the literature (e.g. Nyrnes, 2008), but its reoccurrence here, particularly regarding the question of *entanglement between disciplines* and in the light of the different ontological positionalities of the researchers, illustrates that it is an underlying tension.

A rich seam of questions arose regarding interdisciplinary teaching and learning, both in terms of students' attitudes towards the individual disciplines, and the consequent challenges for educators:

> *students who liked science were more sort of linear in their process, however they didn't differ too much in the creative approach in the art students, but they felt a bit more confident with the science part but equally uncomfortable with the outcome…How do we introduce an interdisciplinary way of learning? (2nd discussion)*

For the researchers, dialogue between disciplines seemed to lead to a sense of 'freedom', which gave rise to a series of questions about the pedagogical implications of this kind of work:

> *Using art to teach science (and potentially vice-versa?) liberates both teachers and students in their creative process since they are not restricted by the "linearized" process and simplified vocabulary of the science classroom: They use in a non-restricted manner the creative process of the other discipline. This realisation struck me… I am not familiar with the literature, unfortunately, but in the end the issue seems to be that we constrain ourselves too much, and we only feel creative by crossing the borders of the discipline. Why don't we go ahead and allow students to perform or discover creative science experiments in the science classroom? Why don't we let them do art as an actual artist would do? Are we sure they won't understand if we supplement these with proper explanations and foundation work, while keeping the creative aspects? Is traditional assessment the only way?*
> *(post-discussion document, Kostas)*

Again, many of these questions have been addressed in previous research (e.g. Driver, Guesne, & Tiberghien, 1985) but their

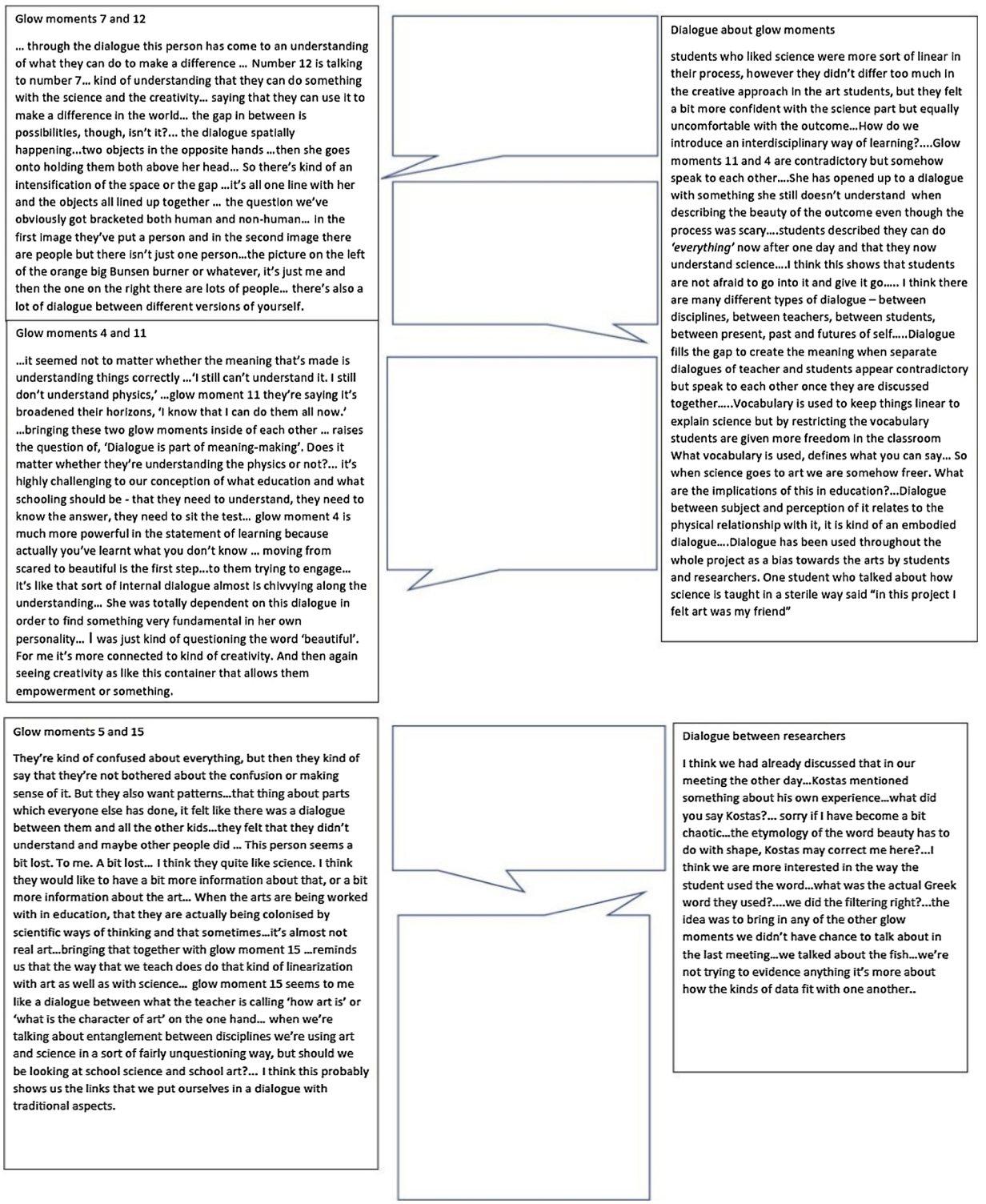

Fig. 10. Dialogue with readers' speech bubbles.

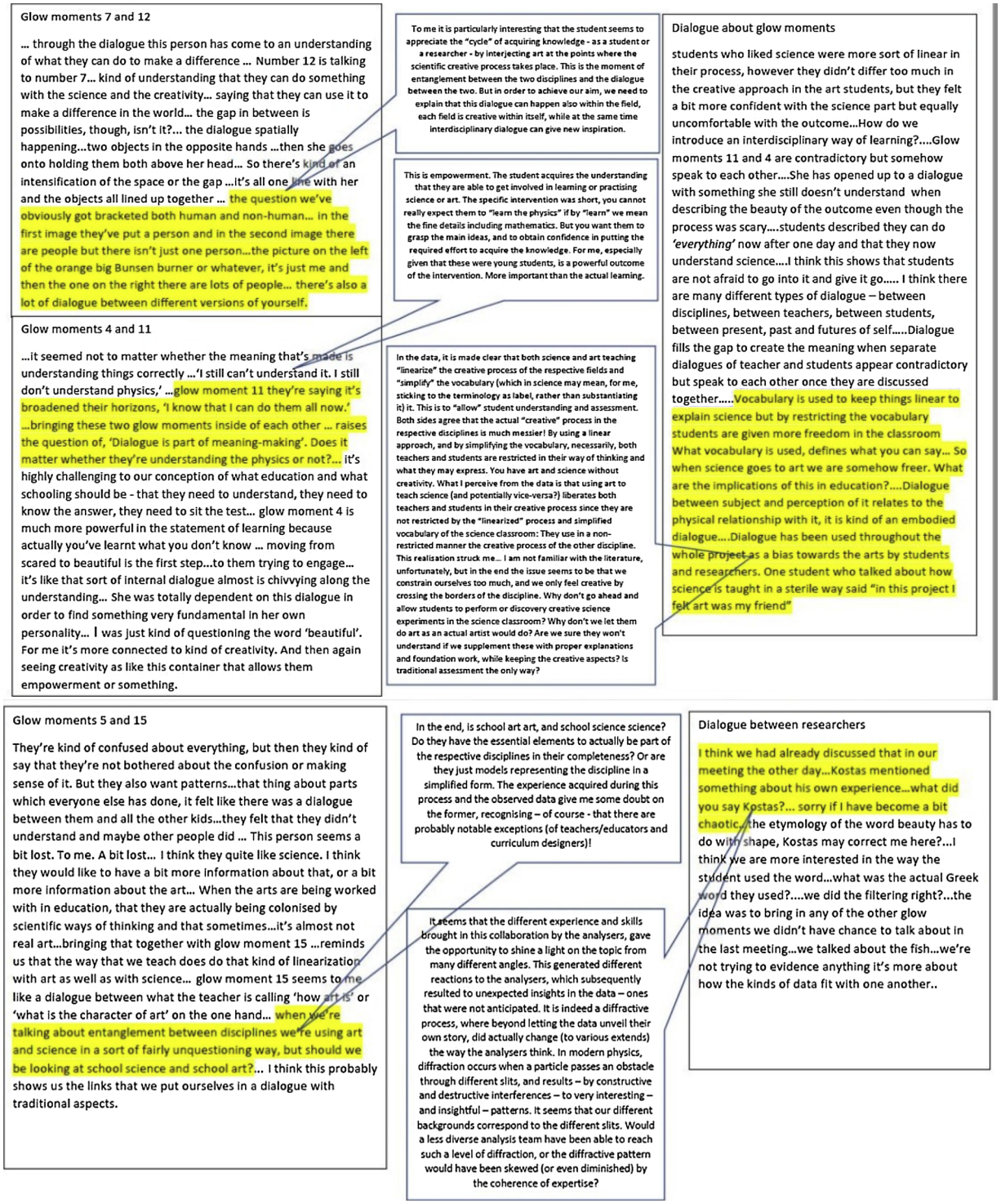

Fig. 11. Dialogue with Kostas' response.

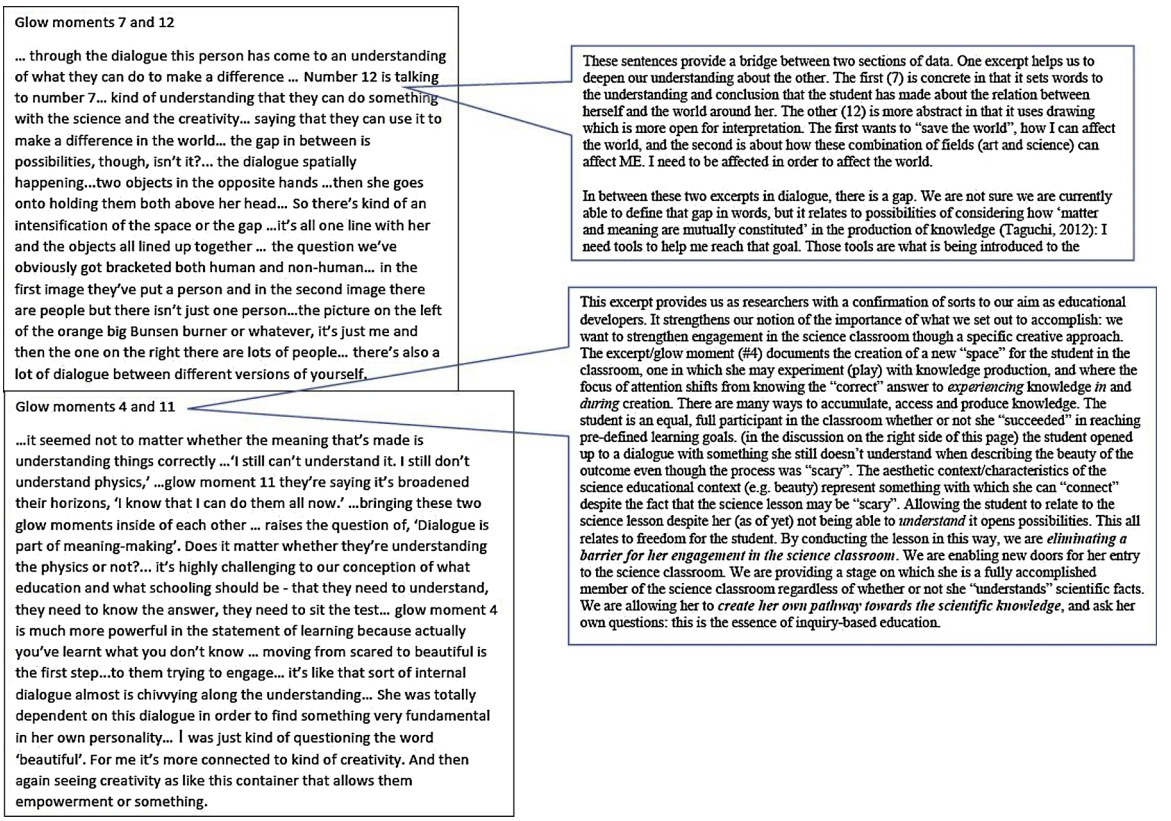

Fig. 12. Dialogue with Janne and Oded's response.

resurgence here in Kostas' mind illustrates adjustments to the 'self-reality' of the researchers. The process of 'dialogue with data' facilitated a shift in positionality which could be reproduced with educators and their pupils.

As well as questions reflecting previous interrogations of science/arts/dialogue, questions arise which appear more novel. A discussion of GM 4 and 11 (both of which were comments taken from student interviews about what they had learned from the Physics and Dance project) prompted the following thoughts from Lindsay:

> '*on glow moment 4 it's saying, 'I still can't understand it. I still don't understand physics,' whereas in glow moment 11 they're saying it's broadened their horizons, 'I know that I can do them all now.'… bringing these two glow moments inside of each other … raises the question of, 'Dialogue is part of meaning-making'. Does it matter whether they're understanding the physics or not?' (2nd half of discussion)*.

[A further question which will be picked up in Diffraction 7 revolves around whether it 'matters' if they are understanding the physics subject matter provokes the possibility of a fundamental pedagogical shift, in which we ask: Does it matter whether students understand the science or not?]

In both discussions, the use of the word 'beautiful' became important, raised by Janne – 'I was just kind of questioning the word 'beautiful'.' (Second half of discussion), and revisited in the subsequent discussion about the glow moment dialogue, where the etymology of the word and its use were interrogated:

> *…the etymology of the word beauty has to do with shape, Kostas may correct me here?…I think we are more interested in the way the student used the word…what was the actual Greek word they used?*
>
> *Second dialogue discussion*

[This consideration of how 'beauty' is conceived in different disciplines and languages leads us to pose a further question for Diffraction 8: How does dialogue between students, teachers and researchers help to diffract meaning of the word 'beauty'?]

[Our final question for Diffraction 7 comes from Kostas, who reflected on the research process by asking: Would a less

diverse analysis team have been able to reach such a level of diffraction, or the diffractive pattern would have been skewed (or even diminished) by a coherence of expertise?]

7. Pausing

We would like to take a pause here, resting for a moment from the diffractive process. There are more diffractions to come for you as the reader and for us as researchers, and because of this we are purposefully not traditionally concluding our process. As Taylor and Gannon (2018) citing Lather (2013:635) state, in this kind of diffractive methodology we are beginning "to do it differently".

However, within this pause, we would like to return to consider our introductory stated aims to revitalize how we articulate dialogue within creative practice; use a diffractive analysis to appropriately make the phenomena tangible; and open up new ways for teachers, students and researchers to experience seeing, doing, feeling and researching science|arts creative pedagogy and to provoke conversations about how this might develop in the future.

7.1. Revitalising dialogue

In terms of revitalising how we articulate dialogue we refer you to our discussion in Diffraction 6, where, for example, dialogue is considered through *matter and* meaning being mutually constituted in the gap of dialogue (Lenz-Taguchi, 2012), and there is a debate as to how dialogue can happen with something that a student does not yet understand; thus recognising an acceptance of 'not-knowing' as possible within dialogue. Moving on from this, we continue to question how dialogue manifests alongside embodiment and materiality in science|arts creative pedagogy, in terms of the relational processes of entangled disciplines *together/with/in/* entangled assemblages of students-teachers-objects-ideas. During our analytic collaging and discussion process, Biesta's concept of education as the emergence of subjectivity was drawn into the flow of our material-discussion. Biesta (2006) develops a concept of the purpose of education to be the emergence of unique human subjects through the teacher-student relationship. The notion that education proceeds through and is characterised by the emerge of the 'new' (in opposition to a notion of education as the transfer of the 'known'[5]) is similar to the relational ontology in both Barad's work and the kind of dialogic education in our theoretical framework (Wegerif, 2007): through education, the actants in the educational intra-action are themselves changed. In Biesta's work, these actants are teachers and students and one would usually think of them as teachers' and students' *minds*. In a post-human framework, they could equally be materials or bodies (both human and other-than-human).

This then raised the question towards the end of the flow of our diffractions, 'What does decentering the human do to our notion of creative pedagogy, and our articulation of dialogue within this?' In the kinds of fluid entanglements and dialogic spaces developed in this project and explored through diffracting 'glow moments' from the case studies, creativity emerges and is performed through assemblages of teacher-student-material-art-science-ideas. Rather than education being about the emergence through dialogue of unique human subjects, creative arts-science education is about the emergence of unique assemblages in which embodied teachers, students, ideas, and objects emerge. As a team, we have even discussed how we, as humans, now feel de-centred and entangled with the questions and our articulation of dialogic space, creative pedagogy and trans-disciplinarity. This question of what decentring the human, does for how we teach and learn will continue to be explored by members of our team, particularly in light of Wazana Tompkins' (2016) provocation to go further and to focus on the 'undoing of the subject and the category of the human'.

7.2. Benefitting from the diffractive analysis

It matters that we have done this research differently, diffractively – in doing so we have directed attention towards the entangled relationality of trans-disciplinary creative pedagogy. As we have taken you through the two detailed diffractions, we have endeavoured to avoid bracketing out some aspects of education that are often side-lined in deference to ideas or concepts held by individual students and a system which increasingly favours education-as-transmission. In the diffractions, the often side-lined aspects of education that we have forefronted include: the importance of honouring students' flights of imagination when exploring scientific questions; the role of real rather than hypothetical experiences for in depth learning; the inclusion of teachers' and students' life experiences and curiosities; the acknowledgement of the role of emotions, feelings, touch and expression as undertones of interdisciplinary experiences; the power of improvisation as it is used within the arts, also employed as a tool beyond the arts; discussion of how students can use their learning to see how they can make a difference; the provocative question as to whether it matters that the 'right answer' to the science is not fully understood; how confusion can be a useful part of a cyclical learning process; really asking whether 'school' art and science are 'real' art and science; and questioning what it means to experience knowledge in and during creation rather than be told it. We hope that this forefronting and our portrayal of entangled relationality opens out the space of pedagogical approaches educators of all kinds (including ourselves) might attempt.

More fundamentally, we think this portrayal begins to challenge what we think education is and what it is for. If the educational objective is not simply more creative teachers or more creative students, but instead, more creative entanglements which change *reality*, we might think in broader, more different and more creative terms about teaching and learning, and schooling per se.

[5] Although this is also accounted for in Biesta's conceptualization of education as qualification and socialization as well as subjectivity.

7.3. Opening up new ways

As a team we have engaged in new ways of researching science|arts creative pedagogy and offered glimpses into, and provocations about, the relational interaction of science-arts-creativity in educational settings. The process has been highly challenging and humbling, but it is one we will continue with in our own way, perhaps together, perhaps apart. Some of us proceed with questions such as how to further forefront the material and let it lead analysis; and how to keep this kind of new research in conversation with qualitative and statistical analyses in mixed methodology approaches (Mertens et al., 2015). Others have different questions.

We hope that as a reader, you will move on from this article and its many fluid entanglements changed and asking new questions too, big or small, about science-arts-creative pedagogy and its dialogic nature. You may find our next set of diffractive questions helpful, so we offer you the beginnings of Diffraction 7…

8. Beginnings of diffraction 7

What is the role or fit – or indeed misfit – of this kind of entangled transdisciplinarity in current education systems?

How might further investigation of this embodied, felt/material, 'knowing this' of actants help us to work with fluid entanglements? Indeed what does it mean to ask about the 'felt' knowledge of other-than-human actants?

Does it matter whether students understand the science or not?

How does dialogue between students, teachers and researchers help to diffract meaning of the word 'beauty'?

Would a less diverse analysis team have been able to reach such a level of diffraction, or the diffractive pattern would have been skewed (or even diminished) by a coherence of expertise?

….or you may choose to ask your own questions….

Conflict of interest

None.

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Appendix A. Biographies

Oded: I am Head of Department of Arts Education at Western Norway University of Applied Science. I coordinate the Global Science Opera. Research focus: creative educational settings in which inquiry in art and science occurs simultaneously.

Kerry: I am a Senior Lecturer who leads the MA Education Creative Arts and co-leads the Creativity and Emergent Educational-futures Network at University of Exeter. I am passionate about promoting creativity in education and developing alternative 21st Century educational futures.

Heather: I am a PhD student at University of Exeter, a specialist tutor in Plymouth and occasional visiting lecturer on the MA Education Creative Arts course at Exeter. My research focus is Creative Education for an integrated cultural and environmental Empathy

Angelos: I am an education and outreach specialist at CERN, the world's largest particle physics laboratory. Central to my role is to develop sustainable pathways to help make wonder, creativity and innovation indispensable parts of school science education.

Hermione: I am a teacher educator and education researcher specialising in Music. I am interested in how music brings people together and in researching the creative possibilities of music-making between different groups and individuals.

Lindsay: I am an educational researcher and teacher educator with a background in science education. Crucial to my approach in both those roles, I see science as a living, creative discipline that is all about asking questions about the natural world.

Kostas: I am a particle physicist who was strongly involved in the Higgs boson discovery and now tries to complete our understanding on mass generation for matter. I am also interested in inspiring the new generations of scientists and citizens.

Janne: I have a combined background in education, visual arts and theatre-design. I am currently an assistant professor and PhD-candidate at Western Norway University of Applied Sciences. I am researching the connection between creativity and sustainability within the context of transdisciplinary educational projects.

Appendix B. Glow moments

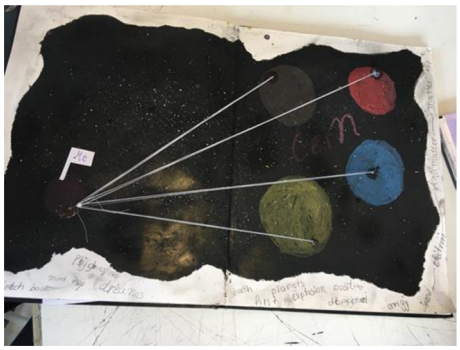
Glow moment 1

Student: In my opinion, it's the expression of our inner world, the expression of our feelings, our most hidden desires and fantasies, which we have the possibility to express in a more creative way either on paper, in music or even in a choreography.

Glow moment 2

S5: I chose the Doppler effect mainly because I had seen it in the Big Bang Theory and its cool that now I know what it is, I can understand the joke in the TV series. And I liked this symmetry it has, because it's very pretty and aesthetically beautiful to watch. The irony is that my final work does not express this but it doesn't matter.

Glow moment 3



And although I'm a little unimportant in relation to the physics and CERN, I contribute to uniting these two fields via this project. That's how I considered myself.

Glow moment 4

S1: Yes, physics was a subject I was forced to do at my previous school and which I didn't like. It was something that was mandatory and not pleasant at all.

Q: Nevertheless, there is a wonder element in physics, right?

S1: Yes there is. But physics was something I couldn't understand and still can't. But now the fact that I don't understand physics is not something scary but in contrast something beautiful.

Glow moment 5

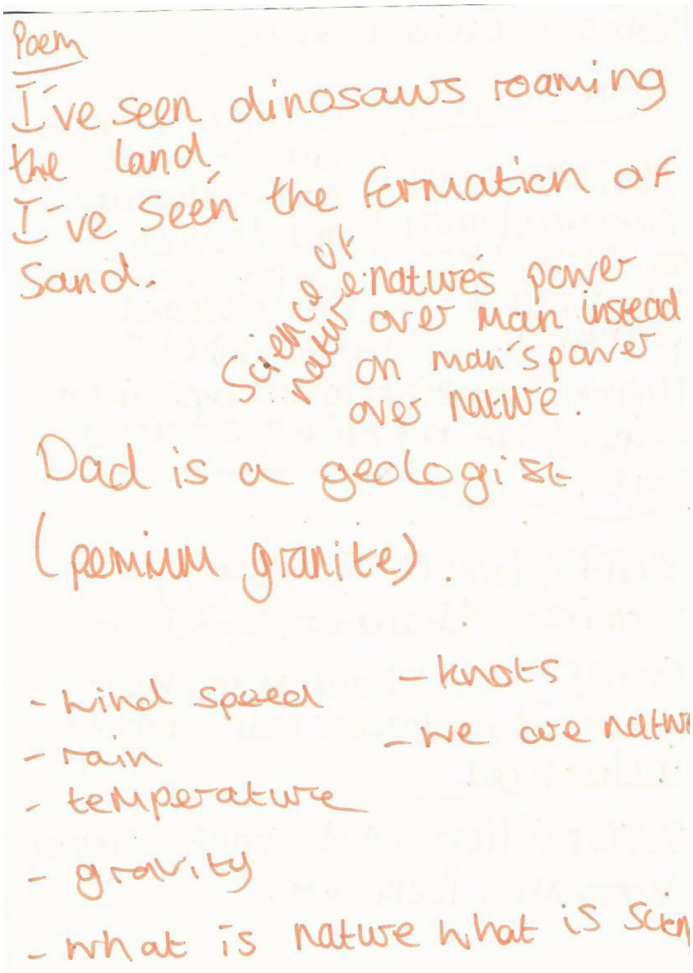
Student: I would probably do it again but I mean this time when we did it there were parts which probably everyone else has done, but I found it confusing why we went to the art galleries looking at pictures and then we were sort of looking at our local area, like the sea and stuff and then I got confused how like we were sort of linking that into our dance and things and I got like the whole science thing. So maybe if like we just did it again sort of like I don't know…just maybe sort of have like clearer patterns and then we can bring like more sort of ideas and put all of it together to sort of make something more…not something that makes more sense, but just something that's sort of more like sort of specific to that one sort of area.

Glow moment 6

Glow moment 7

“It's been exciting to clear up things which I’ve been wondering about regarding the ocean. I think that it was interesting to learn about what I can do to make a difference in the world”.

Glow moment 8



Glow moment 9

Voice 16: "I like the way when you know at the start of the dance. No, was it at the start? I don't know, yeah and we were all doing our own moves. Yeah, I liked the way we didn't know what to do and we was doing all of these actions and then they like put it into something good".

Glow moment 10

Teacher: Well how the girls really… at the beginning didn't have a clue how physics and dance was gonna come together… but how at the end… i really …what the two different subjects totally together and… actually how they learnt about particles through dance, just that movement that they put for each particle is gonna be a way for them to remember the particles.

Interviewer: Yeah, What about the details of your teaching what do you gonna take from it?

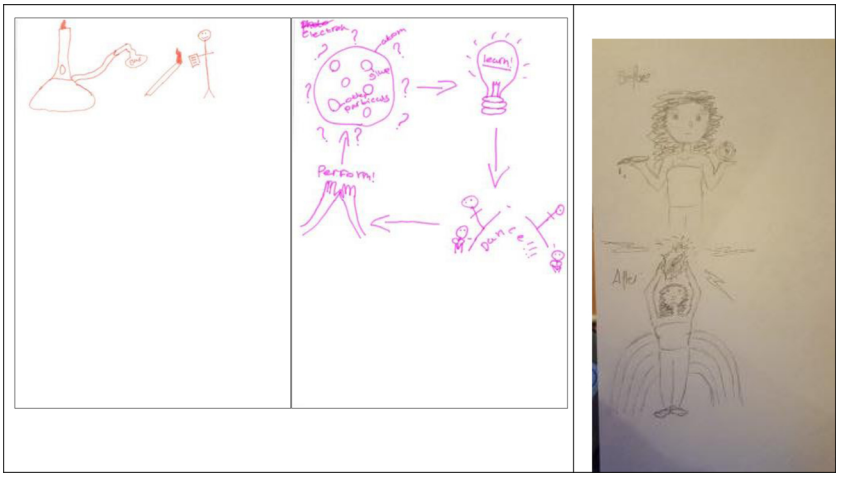
Teacher: Do you know, some of the girls said it… is really interesting because as a dancer i can make dance about everything most things but never in a million years would i have thought I can make dance out of science particles and all that …

Glow moment 11

Interviewer:In general. in this one day, do you think they perceived creativity differently? Teacher: Yeah, I think it has totally open their mind and broadened their horizons, about everything: dance, science, music.

"and this is afterwards me dancing, me learning about science, and doing an investigation because I know that I can do them all now."

Glow moment 12



Glow moment 13

"It was interesting (what the scientist was)….talking about, and how we got to know that the ocean contains much more than (just) fish. It was also interesting how we took that into the drama".

Glow moment 14

"(following these 3 days) I am left with (the knowledge of) how we can make a performance out of improvisation and (scientific) questions. (Also), more knowledge about how fish are, and how the ocean functions".

Glow moment 15

Teacher – "Because we also have to be really prescriptive because we have a set of criteria that we need to meet and that's also not how art is. In the real world. They work in a much messier way. But unfortunately, we also have to make art linear, so that we can understand it and they can understand it, and there's a common ground".

Glow moment 16

Student – Well normally sort of you're sitting there in a classroom, the teacher is blabbing on, telling you certain facts. But with this, you can sort of expand your minds and think about it yourself and sort of discover on your own but with the help of them. And sort of by just discussing simple things like whether I should make it a tube or something, then somehow go onto discussing many facts and science things that I never know, and I sort of learnt from that and then incorporated it into my work.

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